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ON A NEW MOLECULAR PUMP

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A molecular pump which differs considerably from known models is discussed as to its structure and mode of action. In this construction, the commonly used air-gap of a few 1/100 mm is no longer required so that a high degree of operating safety can be achieved. Another advantage of the construction is the considerable evacuation rate of the pump. In spite of the high evacuation rate, a high pressure ratio is obtained at the same time. The final vacuum is limited, for practical purposes, solely by the perviousness of the device and by the emission of gases through the walls. The action of the pump when combined with various backing pumps will be demonstrated by diagrams. Moreover, the fields of application of these pumps will be discussed in some detail.

In 1913, Gaede published his investigations relating to a molecular pump (Fig. 1). The simplest construction consists of a cylindrical casing with a ring-shaped groove which is interrupted at one place, and of a cylindrical runner. The runner is being rotated rapidly by means of an outside drive. The gases will then be pulled along by their friction on the cylindrical runner; they will move in the direction of the arrow. It is possible, when using this arrangement, to connect several steps in series in order to increase the pressure ratio. Instead of several such steps, it is also possible to use a helix-shaped groove as Gaede indicated at that time. This type of construction was later improved further by Holwer (Fig. 2).

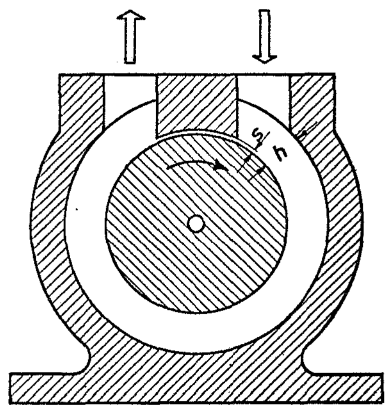


Fig. 1. Schematic drawing of the molecular pump according to Gaede.

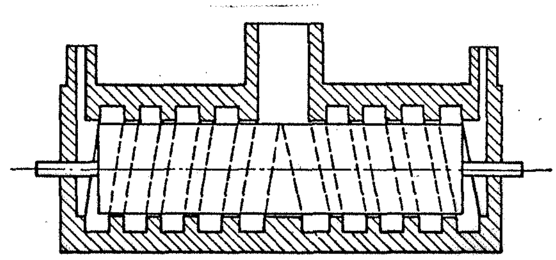


Fig. 2. Molecular pump according to Gaede-Holweck.

Since only a very small air-gap may be permitted to exist between the runner and the casing, Siegbahn suggested a form of construction in which expansions due to heat or to centrifugal forces affect the gap to a very inconsiderable extent only (Fig. 3). Instead of the cylindrical runner, a disc-shaped runner is being used; spiral-shaped grooves have been built into the casing at both sides of the runner.

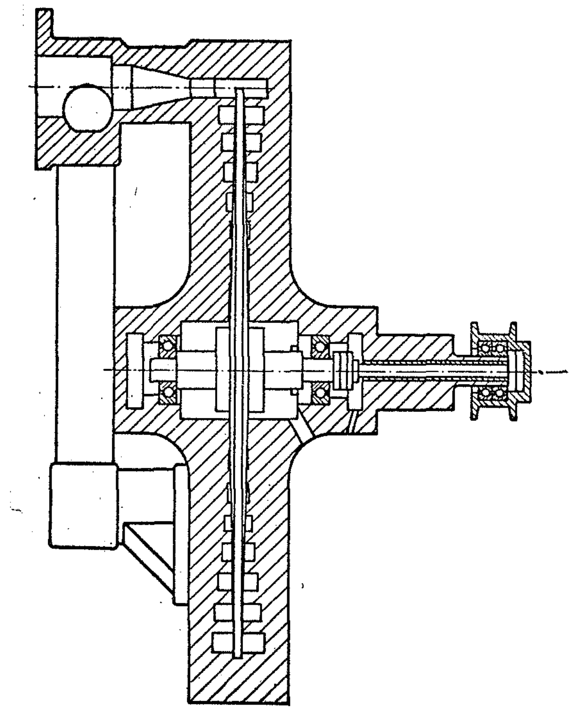


Fig. 3. Molecular pump according to Siegbahn.

In spite of its good features, the molecular pump—regardless of its construction—has had but little success in practice. The following advantageous characteristics should be mentioned: the "high" vapour-free high vacuum, the rapid readiness for operation, and the lacking sensitivity to atmospheric pressure. The reasons why the pump has found so little general acceptance are, on the one hand, the relatively low rate of evacuation when compared to the input, and on the other hand its high sensitivity to foreign bodies or to heat expansion.

The performance of a molecular pump depends, in the known pumps, very considerably on the effectiveness of the packing gap (Fig. 1). Gases will be moved in the packing gap s just as in the operating groove h, due to the friction of rotation, and will come from an area of higher pressure into an area of lower pressure. The pressure gradient between the evacuation side and the pressure side creates an additional stream of gas. On the evacuation side, the gas pulled through the gap s expands and, thereby, places stress on the evacuation side. The calculation of the performance of a molecular pump will have the result, e.g., of a pressure ratio of $1:10^4$ for one step when the gap is infinitely narrow. In practice, however, considerably lower values will be obtained—representing approximately the relation of the depth of the operating groove h to the packing gap s. That means that the operating qualities of the pump will improve with the narrowing of the gap. The pumps known so far have been operating with gap widths of 3/100 to 5/100 mm. But, these narrow gaps involve a grave danger: a sudden influx of air which may deform the rapidly rotating cylinder by the same amount, or a foreign body of the same dimensions as the gap which may penetrate into the pump and lead to the erosion of the runner and, consequently, to the destruction of the pump.

The aim of our development was the creation of a molecular pump that can operate with the largest possible gap, and that, in addition, achieves a high pressure ratio combined with a high speed of evacuation—comparable to that of diffusion pumps. The high rate of revolutions is, by far, not the obstacle that it is commonly assumed to be, provided that there is enough play between the runner and the cylinder so that heat expansions, sudden influx of air, and small foreign bodies will not be able to cause any damage. I wish to refer to the fact that modern kitchen appliances, such as mixers, run with a rate of revolutions of 14,000/min., without the occurrence of any special difficulties. Much higher rates of revolutions are common in the engines of modern jet airplanes.

Fig. 4 is a schematic drawing of the structure of the new pump. The stator plates 2 and the runner 3 are located in the casing 1. The stator plates have been mounted in fixed positions within the casing, while the rotor plates have been mounted on the axis and are rapidly rotated by that axis. All the plates have oblique slots which are arranged in such a way that the slots of the stator plates represent mirror images of the slots of the rotor plates.

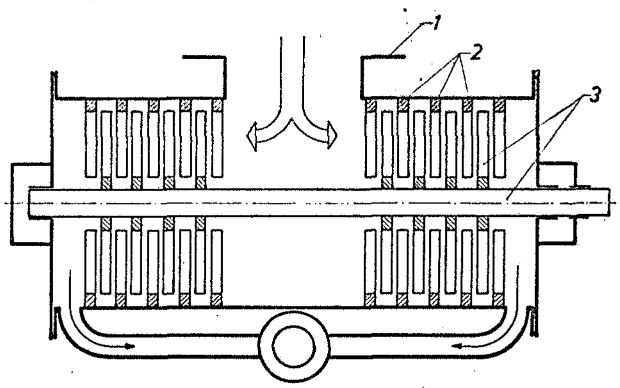


Fig. 4. Schematic drawing of the new molecular pump.

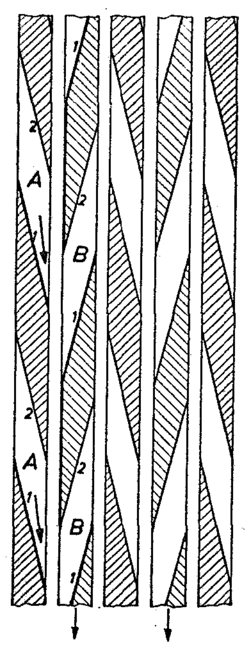


Fig. 5. Performance of the rotor-plates and stator-plates.

We look at Fig. 5 for a better understanging of the <u>modus operandi</u>. That illustration shows the performance of a few rotor plates and stator plates. Let us look first at a groove A in the first stator plate. The wall marked 1 forms, together with the total surface of the second rotor plate, a wedge-shaped channel. In this channel, the gas moves in the direction of the arrow.

The wall 1 of the groove B in the rotor plate also forms a channel with the surface of the stator plate, and again, a moving effect takes place. At the same time, the wall 2 of the same groove in the rotor plate forms, together with the surface of the nearest stator plate, a wedge-shaped channel, and once more, the gas will be pulled in the direction of the arrow. That process is repeated for all the plates. If relatively thin plates—of a thickness of a few millimeters, e.g.—are chosen, only short channels and thereby a low pressure ratio, are obtained in one plate, but on the other hand, it will be possible to mount many pairs of plates so that a high total pressure ratio will, nevertheless, be obtained. Due to the small pressure ratio of one pair of plates, the distance of the plates from each other affects the pressure ratio and the speed of evacuation but little so that it will be possible to select distances of the plates that may be 1 mm or larger, without encountering any difficulties, and without changing the operating properties in a noticeable way. But, at the same time, many channels operate parallel to each other. In the case of the pump shown in the immediately following illustrations, there are 40 operating channels; thereby, a high speed of evacuation will be achieved. Likewise, radial slots between the rotor and the casing may be built with a width of 1 mm, without any further difficulty, because the quantity of air that will flow back, due to the pressure gradient, will be still small as compared to the evacuation velocity. The pump shown has a slot of 1 mm, and the distance of the plates from each other also amounts to 1 mm.

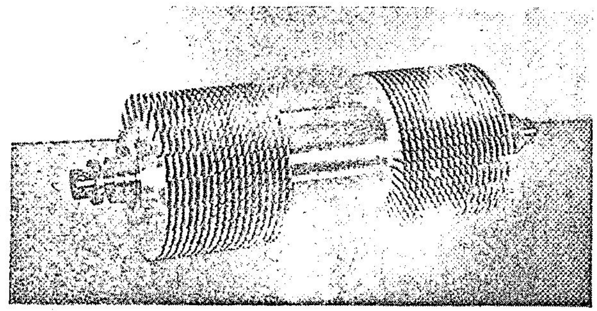


Fig. 6. Rotor of the new molecular pump.

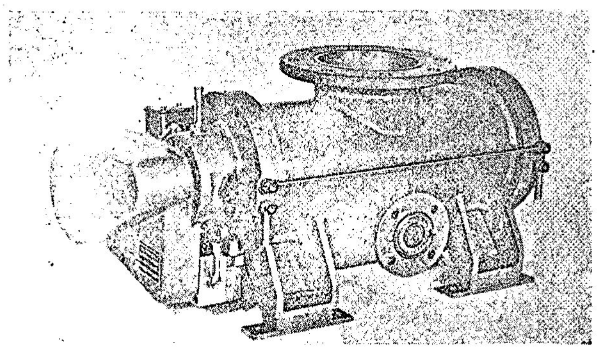


Fig. 7. View of the new molecular pump.

Fig. 6 presents a photograph of the runner. When the angle under which the grooves are milled into the plates is chosen to be small, then a high pressure ratio, together with a low speed of evacuation, will be obtained. If a very large angle is chosen, however, then a high speed of evacuation will be obtained, together with a low pressure ratio. The plates that are directed toward the center of the high-vacuum side present a large angle for high evacuation speed, while the outer plates which act as backers have low evacuation velocities accompanied by a high pressure ratio.

Fig. 7 shows an execution of the pump. The diameter of the runner amounts to 170 mm, and it runs at a rate of 16,000 rpm. The ball bearings are supplied with a continuous flow of oil by means of a feed pump whereby lubrication and cooling are assured. It is driven from the outside by a standard polyphase induction motor of 0.3 kW, by means of a belt transmission.

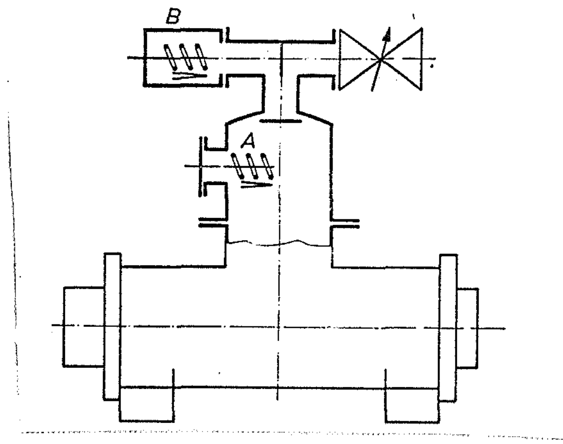
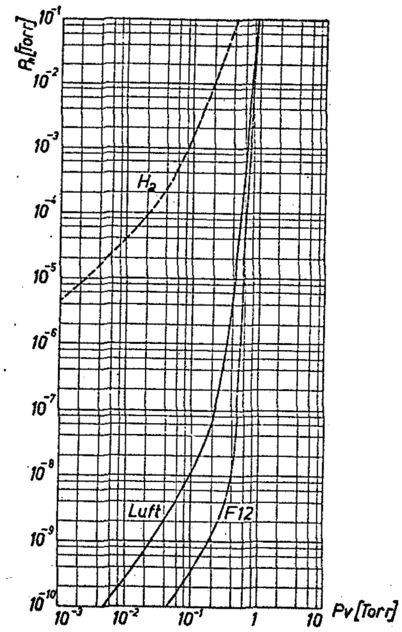


Fig. 8. Schematic drawing of the arrangement of the measuring devices.

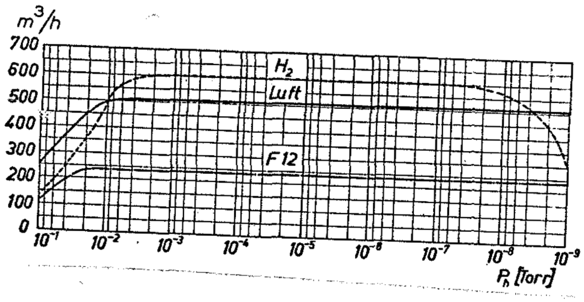
Fig. 8 is a schematic drawing of the measuring devices. The entire structure consists of welded steel with metal packings. At both the locations A and B, the measuring systems of an ionization vacuum-meter according to Alpert has been built in. On the upper right, a needle valve has been mounted to serve as a gas inlet. The tube communicating between the two measuring chambers has been dimensioned in such a way that, at the maximum speed of evacuation, a pressure ratio of 1:8 will exist between the two measuring sites. That measuring section was calibrated in the area ranging from 10^{-4} to 10^{-6} Torr because, in that area, the air that is allowed to come in through the needle valve can still be determined with sufficient precision. In the case of lower pressures, the speed of evacuation was determined on the basis of the pressure ratio of the two measuring sites. The final vacuum achieved during the tests amounted to 5 times 10^{-10} Torr. The residual gas was hydrogen.



Luft = Air

Fig. 9. Dependence of the high vacuum on the rough vacuum, for different gases.

The next illustration demonstrates the dependence of the high-vacuum on the rough vacuum ["Vorvakuum"]. Curve 1 applies to the air, curve 2 applies to hydrogen, and curve 3 applies to the refrigerant F 12. While the pressures obtained are high, the pump has a relatively small pressure ratio. When the transition to the molecular field takes place, the pressure ratio increases rapidly, and it obtains its maximum value when the rough vacuum amounts to 10^{-2}. It depends largely on the molecular weight of the gas to be moved. The maximum pressure ratio for hydrogen amounts to 1:250; for air it is 1:5 times 10^7. The maximum pressure ratio for absolutely pure F 12 (Frigen 12) is, theoretically, still much higher as may be seen by the diagrams.



Luft = Air

Fig. 10. Evacuation speed for various gases.

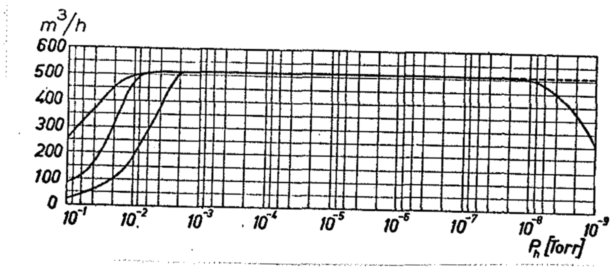


Fig. 11. Dependence of the evacuation speed on the high vacuum, for various backing pumps, in the case of air.

The next illustration shows the evacuation velocity of the pump as dependent on the pressure of the high-vacuum side, with a backing pump of 45 m^3/h. It is worthy of attention that the evacuation speed for hydrogen is higher than the evacuation speed for air even though only a very considerably smaller pressure ratio is effective in the case of hydrogen. The higher evacuation speed is due to the fact that the flow resistance within the slots is considerably lower for hydrogen than for air. When compared thereto, the pump reaches only a smaller evacuation speed in the case of the refrigerant F 12 because, here, the throttling effect of the slots is smaller. The evacuation velocity for the air ranges from 10^{-2} to 10^{-8} Torr constant 500m^3/h and decreases slowly thereafter. When the evacuation speed is determined solely for the partial pressure of the air, without taking into account the residual pressure which consists of hydrogen, then the evacuation speed will remain constant even beyond 10^{-9} Torr. The measured final vacuum was largely determined by the hydrogen which either diffused through the steel walls or was freed from them.

The next illustration, Fig. 11, shows the evacuation speed for air as dependent on the pressure exercised on the high vacuum side in the case of various backing pumps. The upper curve was registered by a two-stage pump combination which had an evacuation speed of 45 m^3/h; the second curve corresponds to a two-stage pump that had an evacuation velocity of 10 m^3/h, and the bottom curve corresponds to a two-stage rotating pump with an evacuation speed of 2.5 m^3/h. As may be seen, the evacuation speed changes only in the area of high pressures with the backing pump.

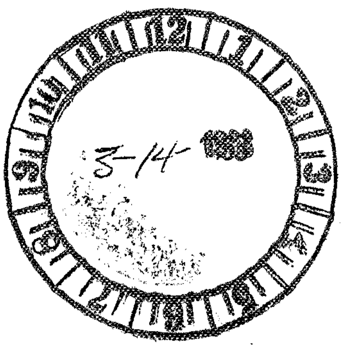
The construction of an installation for vacuum techniques, in connection with the pump described above, is very simple, particularly when a frequent repetition of the evacuation is intended. The pump may be connected directly with the recipient—without insertion of any valve—and it is also possible to connect the backing pump directly with the molecular pump, without any valve. Both pumps may be started simultaneously, at atmospheric pressure. By the time when the backing pump reaches the area of approximately 10^{-1} Torr—this generally takes some five minutes—the molecular pump has already reached its final rate of revolutions and takes over the further pumping process until the desired vacuum has been reached. Even a sudden irruption of air, up to the atmospheric pressure, does not damage the pump at all. A slipping clutch of the engine sees to it that the engine cannot be overburdened. At atmospheric pressure, a low rate of revolutions of the pump occurs which increases as the pressure falls and already reaches its full rate at 10 Torr. The molecular pump described may be used advantageously wherever the stress is on a vacuum that is absolutely free of oil. The pump is superior to a diffusion pump in the area ranging from 10^{-1} to 10^{-3} Torr because it reaches its full evacuation velocity as early as 10^{-2} Torr.

Right now, various applications of the new molecular pump can be recognized where it is likely to be superior to the high vacuum pumps used so far:

Manufacture of large emitting tubes for highest frequencies; accelerators for nuclear physics; mass-spectrometric high-vacuum installations; smelting installations for highest degrees of purity, e.g., of Germanium and Silicon.

The pump might also be usable for the separation of light isotopes. For normal hydrogen, it has a compression ratio of 1:250, while the compression ratio rises to 1:2,400 for heavy hydrogen D_2 so that one may speak of a separating factor of 9.6.

Experiments in that direction are still under way.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